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SOME INTER-RELATIONSHIPS BETWEEN DECOMPOSITION OF VARIOUS PLANT RESIDUES AND LOSS OF SOIL ORGANIC MATTER AS MEASURED BY CARBON-14 LABELLING

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The addition of fresh plant material to soil has been reported to accelerate the decomposition of indigenous soil organic matter. This claim has been tested at Beltsville, Maryland using C^{14}-labelled tissue of tops and roots from several crop plants of different maturity stages and C/N ratios.

Two treatments were made on a Prairie soil from North Dakota containing 3·5 per cent carbon. In one, the previously stored soil was incubated for two weeks before adding the plant material, and in the second, there was no preincubation. One per cent of C^{14}-labelled soybean, wheat or corn plant tops or roots was added to the soil and incubated in a closed system. The evolved CO_2 was absorbed in standard NaOH solution that was sampled and titrated at intervals and the C^{14} counted by liquid scintillation.

In experiments where the soil was not preincubated, a slight increase in soil carbon loss was observed with the addition of mature corn leaves, 28-day-old soybean tops, mature soybean tops or roots. A reduction in soil organic matter loss was found with the addition of young corn tops or roots, mature corn stalks or roots, wheat straw or roots (both young and mature), 28-day-old soybean roots, and 44-day-old soybean tops or roots.

When the soil was preincubated before addition of the plant material all plant parts reduced soil carbon loss significantly except immature soybean roots. The addition of corn roots and wheat roots reduced soil organic matter loss about 50 per cent. Adding fertilizer nitrogen at rates of up to 400 p.p.m. N in the soil, reduced, but did not eliminate, the protecting effect shown by the corn roots and wheat roots. This indicates that C/N ratio is not a major factor.

These results show that fresh plant residue frequently has a protective effect on indigenous organic matter and that this is not directly related to the maturity or N content of the plant tissue. The strong suppression of decomposition by root residues of wheat and corn suggests that some toxic compound is involved.

Selon certains chercheurs, l'adjonction au sol de substances végétales fraîches accélérerait la décomposition des matières organiques naturalles. Pour contrôler cette hypothèse, on a procédé à Beltsville (Maryland) à diverses expériences avec des tissus, marqués, au carbone-14, de parties aériennes et de racines de plusieurs plantes se trouvant à des stades de maturité différents et présentant divers rapporsts C/N.

Deux traitements ont été effectués sur un sol de Prairie du Dakota du Nord, renfermant 3·5 pour cent de carbone. Dans un cas, les échantillons de sol prélevés depuis quelque temps déjà ont été in-

cubés pendant deux semaines avant l'adjonction de substances végétales; dans le second cas, il n'y a pas eu d'incubation préalable. On a ajouté au sol 1 pour cent de parties aériennes ou de racines de soja, de blé ou de maïs marquées au carbone-14 et l'on a ensuite mis le sol à incuber en système fermé.. Le CO_2 libéré a été absorbé dans une solution standard de NaOH, dont des échantillons ont été titrés à intervalles et où l'on a mesuré le carbone-14 avec un scintillateur liquide.

Dans les expériences sans incubation préalable, on a constaté que l'addition de feuilles de maïes mûres, de parties aériennes de soja de 28 jours et de parties aériennes ou de racines de soja mûr entraînait un légère augmentation des pertes du sol en carbone. On a observé une diminution des pertes en matières organiques dans les cas d'addition de parties aériennes ou de racines de jeune maïs, de tiges ou de racines de maïs mûr, de chaume ou de racines de blé (aussi bien jeune que mûr), de racines de soja de 28 jours et de parties aériennes ou de racines de soja de 44 jours.

Dans le cas des échantillons de sol pré-incubés avant l'addition de substances végétales, toutes les adjonctions, sauf celle de racines de soja non encore mûr, ont réduit de manière significative les pertes en carbone. L'adjonction de racines de maïs et de blé a fait diminuer d'environ 50 pour cent les pertes en matières organiques. L'addition d'engrais azoté dans des proportions allant jusqu'à 400 mg d'azote par kg de sol a atténué sans éliminer l'effet protecteur des racines de maïs et de blé. On peut en déduire que le rapport C/N ne constitute pas un facteur déterminant.

Ces expériences montrent que les débris végétaux frais exercent fréquemment un effect protecteur sur les matières organiques du sol et que ce phénomène n'est pas directement lié au degré de maturité ou à la teneur en azote des tissus végétaux. L'inhibition marquée de la décomposition par les débris de racines de blé et de mais donne à penser qu'un composé toxique intervient.

Se ha referido que la adición de vegetales frescos al suelo acelera la descomposición de las materias orgánicas existentes en éste. Para ver si esto es cierto se han hecho ensayos en Baltsville, Maryland (EE. UU.), utilizando tejidos, marcados con C^{14}, de las partes aéreas y de las raíces de diferentes plantas de cultivo, en distintas fases de madurez y con diversas relaciones C/N.

Un suelo de pradera, procedente de Dakota del Norte, que contenía 3.5 por ciento de carbono, se sometió a dos tratamientos. En uno, el suelo, previamente almacenado, se incubó durante dos semanas antes de añadirle los vegetales, y en el segundo, no hubo incubación previa. Se agregó 1 por ciento de partes aéreas o de raíces de soja, trigo o maíz, marcadas con carbono-14 al suelo, y después se incubó éste en un sistema cerrado. El CO_2 desprendido se absorbió en solución tipo de NaOH, de la que de vez en cuando se sacaron muestras que se titularon y cuyo contenido de C^{14} se determinó con un contador de centelleo en líquido.

En los experimentos realizados sin incubación previa del suelo, se observó que la adición de hojas maduras de maíz, de partes aéreas de soja de 28 días, y de partes aéreas o de raíces maduras de soja producía un ligero aumento de la pérdida de carbono en el suelo. Se halló que la adición de partes aéreas o raíces jóvenes de maíz, de tallos o raíces maduros de maíz, de paja o raíces de trigo (tanto jóvenes como maduras), de raíces de soja de 28 días, y de partes aéreas o raíces de soja de 44 días reducía la pérdida de materia orgánica del suelo.

Cuando el suelo se incubó antes de añadirle los vegetales, todos, excepto las raíces de soja sin madurar, redujeron notablemente la pérdida de carbono del suelo. La adición de raíces de maíz y de raíces de trigo redujo en 50 por ciento aproximadamente, la pérdida de materia orgánica del suelo. La adición de abonos nitrogenados a razón de hasta 400 p.p.m. de N, redujo, pero no eliminó, el efecto protector de las raíces de trigo y de maíz. Esto indica que, en este caso, la relación C/N no constituye un factor principal.

Los resultados obtenidos en estos experimentos demuestran que los residuos vegetales frescos ejercen frecuentemente una acción protectora sobre las materias orgánicas existentes en el suelo, y que esta acción no está directamente relacionada con la madurez ni con el contenido de N de los tejidos vegetales. La fuerte inhibición de la descomposición que ocasionan los residuos radicales del trigo y del maíz hace pensar que en este fenómeno entra en juego algún compuesto tóxico.

INTRODUCTIONS

With the development of tracer techniques using C^{14}, it has become possible to measure the decomposition of indigenous organic matter in soil concurrently with the decomposition of added fresh plant material. Several reports of such studies[2–5,7,14] have shown an acceleration in the soil organic matter decomposition rate as a result of fresh plant material additions. This possibility was indicated by LÖHNIS[10] many years ago when he suggested that the addition of fresh plant material to soil increased the availability of soil nitrogen for plant use. Other reports, particularly in the case of organic soils,[1,15] show no such effect. PINCK and ALLISON,[11] in a critical review of Löhnis' work, made the following statement: "In view of the somewhat erratic results with this greenhouse soil, due to its high content of available nitrogen, it seems that the data lend little support for Löhnis' statements." They also concluded from experiments that were run without tracers that this suggested effect of addition of plant material to soil could not be measured accurately without tracers and that the magnitude of the effect could be of only minor importance.

It is apparent from the foregoing that the addition of plant materials to soil does not always increase the rate of organic matter decomposition. It is desirable to investigate the factors controlling this response in more detail. The experiments reported in this paper concern the influence of decomposition of several plant species and plant parts on the decomposition of soil organic matter when the plant materials are incorporated in the soil.

EXPERIMENTAL PROCEDURES

The C^{14}-labelled plant materials used in these experiments were grown in the biosynthesis chamber located at the U.S. Soils Laboratory, Beltsville, Maryland. A complete description of this facility with procedures for growing the plants is published elsewhere.[12,13] Species and maturity of the plant materials used and their nitrogen and carbon contents are listed in Table 1.

The soil used in these experiments was a Barnes clay loam from the State of Minnesota with 3·53 per cent carbon and pH 7·7. For the decomposition studies, some of the soil samples were preincubated in a moist condition for two weeks and some were not preincubated. This dual approach was used because the artificial stimulation of soil micro-organisms that occurs as a result of drying, storing and rewetting soil could affect decomposition of both indigenous and added organic matter. After the pretreatment of soil, the C^{14}-labelled plant material was added to the soil, and the system was incubated for either 28 or 59 days. In addition, two incubation controls were included, a control for the soil and a control for the C^{14}-labelled plant material. The soil control (without added plant material) provided decomposition rates of indigenous soil organic matter, and the C^{14}-labelled plant material control (incubated in inoculated sand) provided decomposition rates and specific activity data.

In all the experiments, except one, additional mineral nitrogen was added to the soil at the rate of 100 p.p.m. N to prevent nitrogen deficiency. In the other experiment 0-, 100-, 200-, and 400-p.p.m. increments of nitrogen were added with corn roots to investigate the influence of nitrogen and corn roots on soil organic matter decomposition. In another experiment, the influence of particle size of the added plant residue was studied. In addition to the usual 20-mesh grinding, a series of plant materials were ground to pass through a 60-mesh sieve and incubated in the same manner.

The soil and sand were incubated at 27°C with 1 per cent additions of the respective plant materials. Moisture content at the beginning of the incubation was 20 per cent for the soil and 13·3 per cent for the sand-plant material mixtures. A soil suspension was added to the sand to inoculate it with a microflora similar to that inhabiting the soil. In all cases, 75-g samples of soil, in duplicate, were incubated in 500-ml. Erlenmeyer flasks in a closed system with CO_2-free air passing over the soil. The air was washed free of CO_2 by passage through a sintered-glass air dispersion tube to produce small bubbles, through NaOH solution in a large flask, and then washed with water in the same manner. The air flow was controlled by means of a calibrated capillary tube in the air line leading to each Erlenmeyer flask.

The CO_2 evolved during respiration of the soil micro-organisms was trapped in standard 0·25 N NaOH solution in air-washing vessels equipped with sintered-glass air dispersion tubes. The CO_2 was quantitatively recovered in the first vessel, but for radiological safety, a second absorption vessel was attached. The absorption vessels were changed at intervals throughout the incubation period and the contents transferred to volumetric flasks. An aliquot was titrated to determine total CO_2 and a second aliquot used to determine comparative radioactivity levels by means of liquid scintillation counting.

*Table 1. Composition of C^{14}-labelled Plant Parts used in Decomposition Studies**

Plant material	Nitrogen	Carbon
	%	%
51-day-old corn tops	2·84	42·7
51-day-old corn roots	2·34	42·2
Mature corn stalks	1·61	41·9
Mature corn leaves	1·11	41·3
Mature corn roots	1·91	41·9
Immature wheat tops	2·46	42·0
Immature wheat roots	2·22	42·0
Mature wheat straw	1·34	41·3
Mature wheat roots	1.48	42·0
28-day-old soybean tops	4·65	41·0
28-day-old soybean roots	3·04	40·5
44-day-old soybean leaves	4·19	45·5
44-day-old soybean roots	2·70	43·3
71-day-old soybean leaves †	1·48	46·1
71-day-old soybean roots †	1·28	45·9

* The wheat plants were labelled at about 40 μc/g of carbon. All other plant materials were labelled at about 16 μc/g of carbon

† Mature.

One millilitre samples of NaOH solution containing C^{14} were transferred to 20-ml counting vessels and the vessels filled with scintillation phosphor. The scintillation phosphor was of the following composition: 385 ml xylene, 385 ml dioxane, 230 ml absolute ethyl alcohol, 80 g naphthalene, 5 g PPO (2,5-diphenyloxazole) and 50 mg POPOP (1, 4-di [2-(5-phenyloxazolyl)] benzene). This scintillation phosphor is miscible with about 7 per cent of water but will become slightly turbid if more than about 0·06 meq of NaOH is present in the counting sample. The turbidity will not materially reduce the counts if they are counted immediately after preparation, but precipitation will lower the counts if the samples are allowed to stand overnight.

For experiments in which the soil was not preincubated, the incubation intervals were 0·5, 1, 1·5, 2, 4, 8, 14, 28, and 59 days. Since rapid decomposition had subsided by the end of 28 days, later studies on preincubated soils were limited to incubation periods of 2, 4, 8, 14, and 28 days.

RESULTS

The results of the incubation experiments in which the soils were not preincubated before addition of the C^{14}-labelled plant material are given in Tables 2 and 3 for 28 and 59 days, respectively. The control soil carbon loss figures are from soil that was incubated without plant material addition. The three different sets of values represent three experiments. With plant material added to the soil, the losses that were found from soil and from the added plant material are reported in the second and third columns. These values were calculated from the tracer evaluation. The control soil carbon loss minus the soil-carbon loss is a simple subtraction of the second column values from the first column values. Any negative values in the fourth column represent acceleration of decomposition of the indigenous soil organic matter, while positive values represent a decrease of soil organic matter decomposition induced by the addition of fresh plant material. The fifth column gives the per cent of the plant carbon remaining in the soil at the termination of the incubation experiments.

These results show that the majority of plant materials protected the indigenous soil organic matter from decomposition rather than accelerated its loss. Although five cases of acceleration of organic matter loss are shown in Tables 2 and 3, statistical analysis of the data shows them to be no different from the soil control.

The results of incubation experiments in which the soil was preincubated for 14 days before addition of the C^{14}-labelled plant material are given in Table 4. The reported results were obtained in three incubation experiments. The preincubation soil carbon loss ranged from 83 to 88 mg per 75 g of soil. The control soil carbon loss values varied somewhat more with one set at 66 mg, another at 77 mg, and the third at 80 mg carbon loss per 75 g of soil. This degree of variability seems to be inherent in soil incubation experiments.

In these experiments, as was also observed in the earlier experiment without preincubation, the plant tops decomposed more rapidly than their respective roots. Considerably less soil organic matter decomposition was found in a comparable time after addition of the plant material in the preincubation experiments than in the non-preincubation experiments. This, of course, resulted from the disappearance of the readily decomposable fraction during the preincubation.

The preincubation experiments furnished even stronger evidence that the added plant material protected the soil organic matter from decomposition. Increased loss of soil organic matter was obtained only in the case of 44-day-old soybean roots. In contrast, the mature cereal residue markedly retarded soil organic matter decomposition, with the reduction ranging from 28 to 53 per cent. The single negative value reported that would suggest acceleration of soil organic matter decomposition was not significantly different from the soil control.

The data presented in Table 5 are from another experiment similar to those reported in Table 4 except that the plant material was ground to pass a 60-mesh sieve. The results are substantially the same as those reported in Table 4 and again the evidence supports the contention that added plant material protected soil organic matter from decomposition. The negative values for soybeans are again not significantly different from the soil control. The cereal plant parts, except for corn stalks, showed a significant soil organic matter protection.

Table 6 shows the results of an experiment conducted to determine the influence of nitrogen rates on the decomposition of young and mature corn roots in soil and on loss of soil organic matter. When mature corn roots were added to soil, the increments of nitrogen increased the rate of soil carbon loss. Plant carbon loss did not change except for a slight increase with the last nitrogen increment. The mature root material remaining at the end of the incubation period was nearly constant, but decreased with the last increment of nitrogen. When the young corn roots were added to the soil, the addition of 100 p.p.m. of nitrogen decreased both the soil carbon and the plant carbon losses. The values reported in Table 4 where 100 p.p.m. N was added to the soil, correspond fairly closely to the values shown in Table 6 for both the young and mature corn roots at the 100-p.p.m. N rates.

The failure of nitrogen to increase the decomposition rate of the added plant roots is not surprising, because the mature corn roots

*Table 2. Carbon Loss and Balance from Soil and Carbon[14]-labelled Plant Material Incubated for 28 days with the Soil not Preincubated**

Plant material added	Control soil C loss	Plant material added to soil		Soil control C loss minus soil C loss	Plant C remaining
		Soil C loss	Plant C loss		
	mg	mg	mg	mg	%
51-day-old corn tops	136	133	258	3 bcd	19
Mature corn stalks	136	131	268	5 bcd	15
Mature corn leaves	136	140	267	− 4 cd	14
Mature corn roots	136	68	248	68 a	21
Mature wheat straw	146	142	270	4 bcd	13
Mature wheat roots	146	143	231	3 bcd	27
Immature wheat tops	146	126	303	20 bc	4
Immature wheat roots	146	137	231	9 bc	27
28-day-old soybean tops	146	162	295	−16 d	4
28-day-old soybean roots	146	142	241	4 bcd	20
44-day-old soybean leaves	136	114	313	22 b	8
44-day-old soybean roots	136	119	240	17 bc	26
71-day-old soybean leaves†	136	132	245	4 bcd	29
71-day-old soybean roots†	136	125	232	11 bc	32
				LSD 19	

* According to Duncan multiple-range comparisons, means followed by an identical letter do not differ significantly. Means not followed by the same letter differ at the 5 per cent level of significance.(6)

† Mature.

*Table 3. Carbon Loss and Balance from Soil and Carbon¹⁴-labelled Plant Material Incubated for 59 days with the Soil not Preincubated**

Plant material added	Control Soil C loss	Plant material added to soil		Soil control C loss minus soil C loss	Plant C remaining
		Soil C loss	Plant C loss		
	mg	mg	mg	mg	%
51-day-old corn tops	179	174	284	5 bcd	11
Mature corn stalks	179	177	298	2 bcd	5
Mature corn leaves	179	183	298	− 4 cd	4
Mature corn roots	175	99	300	76 a	4
Mature wheat straw	189	186	300	3 bcd	3
Mature wheat roots	189	192	271	− 3 cd	14
Immature wheat tops	189	164	329	25 b	0
Immature wheat roots	189	175	274	14 bcd	13
28-day-old soybean tops	189	202	315	−13 d	0
28-day-old soybean roots	189	180	264	9 bcd	13
44-day-old soybean leaves	175	160	356	15 bc	0
44-day-old soybean roots	175	162	282	13 bcd	13
71-day-old soybean leaves†	175	175	284	0 cd	18
71-day-old soybean roots†	175	170	263	5 bcd	24
				LSD 24	

* According to Duncan multiple-range comparisons, means followed by an identical letter do not differ significantly. Means not followed by the same letter differ at the 5 per cent level of significance.(6)

† Mature.

contained 1·91 per cent nitrogen and the 51-day-old corn roots contained 2·34 per cent nitrogen. values greater than the minimum for normal decomposition. Energy availability and the nature of the plant roots were probably the factors limiting decomposition rate, and the addition of the increments of nitrogen did not influence the availability of energy. The decomposition of the soil organic matter may have been limited by lack of nitrogen even though the decomposition of the residues was not thus limited. In this case the nitrogen increments would favor increased soil carbon loss independently of the residue.

SUMMARY

In no experiment did the addition of plant material significantly accelerate decomposition of the indigenous soil organic matter. Among the 53 cases reported, there were 8 where an indication of accelerated soil organic matter loss was observed. However, none of these cases was significantly different from the soil control. On the other hand, in 22 of the reported cases there was a significant reduction in soil organic matter decomposition with the addition of plant parts of wheat and corn.

Most laboratory experiments using soil incubation techniques are set up with soil that has been dried and stored. Such soils usually show a surge of microbial activity when rewetted. This accentuated decomposition may obscure any additional positive or negative effects of added residue. Most of the reported increases in soil organic matter decomposition have been of a magnitude such that variability

*Table 4. Carbon Loss and Balance from Soil and Carbon[14]-labelled Plant Material Incubated for 28 days Following 14 days Soil Preincubation**

Plant material added	Preincubation soil C loss	Control soil C loss	Plant material added to soil		Soil control C loss minus soil C loss	Plant C remaining
			Soil C loss	Plant C loss		
	mg	mg	mg	mg	mg	%
51-day-old corn tops	86	66	37	288	29 ab	10
51-day-old corn roots	84	77	45	189	32 ab	40
Mature corn stalks	85	80	58	256	22 abc	18
Mature corn leaves	84	66	42	288	24 ab	7
Mature corn roots	84	80	46	209	34 ab	33
Mature wheat straw	85	80	39	283	41 a	9
Mature wheat roots	84	80	37	235	43 a	25
28-day-old soybean tops	88	66	60	308	6 cd	0
28-day-old soybean roots	88	66	65	227	1 cd	25
44-day-old soybean leaves	85	66	65	281	1 cd	18
44-day-old soybean roots	84	66	79	199	−13 d	39
71-day-old soybean leaves†	83	80	58	341	22 abc	1
71-day-old soybean roots†	84	80	63	211	17 bc	39
					LSD 20	

* According to Duncan multiple-range comparisons, means followed by an identical letter do not differ significantly. Means not followed by the same letter differ at the 5 per cent level of significance.[6]
† Mature.

*Table 5. Carbon Loss and Balance from Soil and Carbon[14]-labelled Plant Material Ground to Pass a 60-mesh Sieve. Incubated for 28 days following 14 days' Soil Preincubation**

Plant material added	Preincubation soil C loss	Plant material added to soil		Soil control C loss minus soil C loss	Plant C remaining
		Soil C loss	Plant C loss		
	mg	mg	mg	mg	%
Control, no plant material	87	70	—	0 cd	—
Mature corn stalks	87	58	237	12 bc	24
Mature corn roots	88	37	194	33 a	38
Mature wheat straw	89	53	221	17 b	29
Mature wheat roots	89	44	208	26 ab	34
71-day-old soybean leaves †	86	80	300	−10 d	13
71-day-old soybean roots †	86	78	194	− 8 d	44
				LSD 14	

* According to Duncan multiple-range comparisons, means followed by an identical letter do not differ significantly. Means not followed by the same letter differ at the 5 per cent level of significance.[6]
† Mature.

*Table 6. Carbon Loss and Balance from Soil and Carbon^{14}-labelled Corn Roots Treated with Several Nitrogen Rates and Incubated for 28 days, following 14 days' Soil Preincubation**

Plant material added and nitrogen rates	Preincubation soil C loss	Plant material added to soil		Soil control C loss minus soil C loss	Plant C remaining
		Soil C loss	Plant C loss		
	mg	mg	mg	mg	%
Control, no plant material	76	77	–	–	–
Mature corn roots. No N	82	35	202	42 a	36
Mature corn roots. 100 ppm N	82	37	189	40 ab	40
Mature corn roots. 200 ppm N	82	43	188	34 bc	40
Mature corn roots. 400 ppm N	86	54	221	23 d	30
51-day-old corn roots. No N	82	56	223	21 d	29
51-day-old corn roots. 100 ppm N	84	45	189	32 c	40
				LSD 7	

* According to Duncan multiple-range comparisons, means followed by an identical letter do not differ significantly. Means not followed by the same letter differ at the 5 per cent level of significance.[6]

in the results of the order reported herein would have changed them from positive to neutral or negative results.

The possibility exists that some soils may actually lose soil organic matter because of the addition of fresh plant material. Soils and organic matter differ very markedly in their formation and nature. JOFFE[8] when dealing with the principle of soil zonality, suggested that organic matter formed in one zone may be significantly different from organic matter formed in another zone. Organic matter formed in the Prairie soils may be more susceptible to decomposition than organic matter formed in the semi-tropical areas. Possibly, green manuring would not reduce the organic matter content of soils in zones where the more resistant soil organic matter is found. This should be true of the soils in the Southeastern United States.

Another factor that may be of influence is the relationship of the amount of plant material added to the soil to that already present. In an area where the soil organic matter is readily susceptible to decomposition, the addition of a quantity of plant material that is large in comparison to the organic matter already present may be expected to accelerate the decomposition of the soil organic matter. The addition of a quantity of plant material that is small in comparison to the amount of indigenous soil organic matter would not be expected to exert an appreciable influence on the decomposition of the soil organic matter. The reports of BINGEMAN, *et al.*[1] and STOTZKY and MORTENSEN[15] of organic matter decomposition in organic soils bears out this latter idea. The stage of maturity of the added plant material may also influence decomposition of both the added plant material and the soil organic matter.

The previously unreported observation that the roots and some top parts of corn and wheat plants reduce the rate at which soil organic matter is decomposed, is in line with observations that have been made in the field for many years that grass crops[9] and corn do not deplete soil organic matter, but instead with proper management and nutrition, both of these crops will maintain or increase the organic matter content. Most of the wheat in the U.S.A. is grown in an area where moisture is the limiting factor so it has been impossible to develop wheat yields to the same extent as corn yields. Consequently, little information is available about the organic matter regime under wheat with optimum nutrition and growth. The possibility exists that wheat, too, would maintain soil organic matter if maximum yields were obtained. It is also possible that the nature of the wheat plant has prevented the organic matter content of the soil from declining at a much more rapid rate than has been observed.

The possibility that the protection of soil organic matter reported in this paper may have resulted from limited decomposition of the added plant materials because of either nitrogen deficiency or particle size considerations was investigated. The nitrogen rate experiment showed that increments of nitrogen did not increase the rate of decomposition until the highest rate was reached, and this was not a large increase. The protection of soil organic matter was decreased with nitrogen increments from 55 to 26 per cent. Particle size also seemed to be only a minor factor in the rate of decomposition of the added plant material. These observations reduce the possibility that the protective effect is a C/N ratio effect or is the result of slow decomposition of the plant material because of particle size considerations.

The question of the mechanism of the protective effect still remains. One of the obvious possibilities is that the plant material contains some substance that is toxic to the soil microorganisms that limits for a time the decomposition of the added plant material and at the same time protects the indigenous soil organic matter and reduces its rate of decomposition.

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DISCUSSION

D. Sauerbeck *(Germany)*: (1) I would like to know if you have done similar experiments on a soil of lower carbon content? A negative priming effect such as that shown in your paper was found by Bingeman *et al.* using an organic soil. It may be that negative priming actions occur in any soil with a fairly high carbon content. A carbon content of above 3 per cent, as in your experiments, is rather high and the results may be different on a low carbon soil. (2) I wonder if the effects shown in your paper may not be due to the relatively high rate of addition. Would the results be the same at rates similar to those occurring in the field?

J. H. Smith *(U.S.A.)*: (1) I used only one soil and so have no results with a low carbon soil. (2) It has been observed that the larger the addition of plant material the more extensive is decomposition. I would expect some protection of organic matter even with a low rate of application of plant material. I feel that the rate used in this experiment may be a little high but still realistic and in line with the amount of tops and roots added to a soil where a large corn crop is grown and only the corn removed.

W. V. Bartholomew *(U.S.A.)*: We have found both stimulation and repression in our work on the influence of new organic residues on the decomposition of native organic matter. The differences we attribute to the kind of soil. Total quantity of organic matter in the soil has not always been correlated with the occurrence of stimulation.

D. S. Jenkinson *(United Kingdom)*: We agree with Dr. Smith in finding that losses of both unlabelled and labelled carbon are increased by air drying.

D. Sauerbeck: This effect has been observed only in our high-carbon soil I. In the low-carbon soil II drying and rewetting did exert some effect on the decomposition of the added plant carbon. This is probably because on soil II the plant carbon was a much larger proportion of the total decomposing mass than in soil I. It is a question of the ratio of plant carbon to soil carbon.

J. H. Smith: The type of soil organic matter and the climatic zone in which it was formed will determine its stability and resistance to decomposition. The content of organic matter alone is not an adequate basis for making predictions of the stability or instability of soil organic matter.